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Transforming tradition: The *aflaj* and changing role of traditional knowledge systems for collective water management

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ABSTRACT

Living in a harsh, desert climate, Omani rural communities have developed locally-appropriate knowledge to deal with water scarcity. Similar to the *qanat*, the *aflaj* taps into the natural water table and uses a gravity system to channel water through underground channels to villages. Traditional techniques of water management, such as the *aflaj*, represents a way of adapting to and coping with difficult climates which have persisted for millennia. However, knowledge systems have often 'decayed' with the onset of modernity. These management systems, which developed concurrently with early Omani date palm cultivation, have defined customary and hereditary water rights which are in decline. This article uses Ostrom's Common Pool Resource (CPR) framework, which prioritises the collective management of shared resources to maximise the benefit for all involved and avoid diminishing benefits that are created by the pursuit of individual goals. Using this framework, this article's evaluation of the literature found that traditional *aflaj* management systems have a great capacity to evolve and, therefore, the *aflaj* represents both a dying system, and a potential for climate adaptation. Historically, *aflaj* have been managed by ancient water users associations, which provide social controls and govern usage norms. The findings of this review are that the *aflaj* system's ability to respond to pressures of modernity from competing institutions, including markets, and embedded social capital mechanisms will influence its capacity to mitigate uncertain hydrology and climate. This article suggests ways in which the management of the *aflaj* can adapt to a multiple institutional framework to 'transform' collective water management.

1. Introduction

The *aflaj* subterranean tunnel-well system is the most common form of water management in Oman (Dutton, 1989; Zekri and Al-Marshudi, 2008). With precipitation rates of less that 100 mm per annum and a desert cover of 80% (FAO, 2008), the adaptability to harsh climatic conditions has been central to Omani communities' survival (Häser et al., 2010). The *aflaj,* fed by mostly alluvial aquifers, represents one of these adaptations. Oman has several important aquifers which are the alluvial aquifers, the regional Quaternary aquifers, the aquifers of the Hadramawt Group and the Fars Group (FAO Aquastat, 2008). Groundwater is most abundant in the North and South of Oman where the water is most frequently recharged (FAO Aquastat, 2008). However, the changing precipitation rates, and increasing risk of drought means that several previously renewable groundwater sources are now slow to recharge (FAO Aquastat, 2008). As shown in Table 1, there is currently a deficit in the groundwater balance. However, depletion of groundwater varies regionally and therefore some areas may have a greater deficit than others.

This groundwater deficit compounds increasing desertification rates in a country which is already largely desert (Al-Hashmi, 2013). There are predictions that, despite Oman's reliance on subterranean water sources, groundwater will be increasingly saline with predicted increases in temperature, and greater land degradation for the entire Gulf Cooperation Council (GCC) area (Elasha, 2010).

Oman is divided into five regions which are Al Dakhiliyah, Al Batinah, Al Wusta, Ash Sharqiyah and Al Dhahirah, classified as either hyper-arid or arid (Al-Hashmi, 2013). Oman's geography has11 physiographic regions which can be divided into plains, wadis and mountains (Al-Hashmi, 2013). As shown in Table 2, the *aflaj* prevalence differs regionally (the term *aflaj* is plural; the singular is *falaj*). Like the *qanat* system, the *daudi aflaj* system (i.e. *aflaj* with underground channels and ventilation shafts) has existed in some form in Oman since the pre-Islamic era (Lightfoot, 1996; Remini et al., 2014).

This paper uses Ostrom's Common Pool Resource (CPR) framework to analyse the extent to which the institutions governing the *daudi aflaj* can adapt to modernisation. The paper does this by considering the potential of the Ostrom's collective action theory to revitalise the

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Table 1
Groundwater balance in Oman (MCM/yr source: FAO, 2008).

Rainfall	Groundwater Recharge	Agricultural Use	Domestic and Industrial Use	Total Use	Deficit
9481	1267	1487	158	1645	−378

declining system. Using Ostrom (1990: 30) seminal definition, a CPR is defined as 'a natural or man-made resource system that is significantly large as to make it costly (but not impossible) to exclude potential beneficiaries from obtaining benefits from its use'. For example, an aquifer is of such a size that it is very difficult to prevent another person from extracting groundwater for their use – or even over-abstracting this resource. The difficulty of this system is that it becomes hard to manage individual consumption of a resource even when it is to the detriment of other users (for example, through individual tubewells depleting aquifer levels). In the case of the *aflaj*, the CPR is the aquifers which the system uses to produce water.

Within this framework, collective action promotes the sustainable management of the CPR through the organisation of individuals and institutions to manage the resource within a system of norms and social behaviour which govern its use (Ostrom, 1990). With the historical development of the *aflaj*, methods of management, which included 'codes of social behaviour' evolved around the system (Sutton, 1984; Adeel, 2008). This article explores how these codes of behaviour are embedded within traditional knowledge systems which have governed community management of water in Oman. The article further explores how traditional knowledge has further codified systems of equitable and sustainable use in the form of land rights (Buerkert and Schlecht, 2010).

The research question that this article sets out to answer is: how can the collective action framework lead to improved management of the *aflaj* in modernity? The paper aims to use Ostrom's collective action framework to examine where traditional knowledge systems can adapt to promote sustainable water management and reinstate the *aflaj* in Oman by promoting collective action, and identifying the difficulties in current *aflaj* management which limit the ability of the management system to adapt.

2. Background

2.1. The origins, diffusion and variants of the qanat

The origin of the Omani *daudi aflaj* is from the Persian system of *qanats* which likely originated in Iran, although the provenance is not fully agreed upon (Fattahi, 2015). Estimates of the date of origin are also contentious, with most estimates in Iran around 700 B.C (Lightfoot, 2000; Martinez-Santos and Martinez-Alfaro, 2012). However, as Kamash (2006) reports, the other theory argues that the *qanat* originated in the Arabian Peninsula between 1000 and 600 B.C. Estimates for Oman suggest that the *aflaj* have been operating for 1500–2000 years (Dutton, 1984; Al-Marshudi, 2007).

Historically these systems developed in arid and semi-arid environments that are characterised by low rainfall and dependent on specific hydrological, topographic, climatic and geological conditions, which are necessary for the system to function (Lightfoot, 2001; Kamash, 2012). As Lightfoot (2001: 6) extensive work on the diffusion of *qanats* states: '*qanats* are very often found originating at the base of hills or mountains, where water from alluvial deposits or bedrock aquifers in these highland regions can be directed onto adjacent valleys or basins, but they are not found up in the highlands'.

As shown in Fig. 1, which depicts a typical Omani *daudi aflaj,* the *qanat* system taps into alluvial aquifers using a vertical tubewell or 'motherwell' (Al-Ghafri et al., 2003; Lightfoot, 2001). Using gravity, water flows into a gently sloping subterranean tunnel which begins at the base of the motherwell to end in a village or fields (Al-Marshudi, 2001;English, 1968). The subterranean channel can extend for tens of kilometres (Al-Marshudi, 2001) and the landscape is punctured by shafts at different intervals which connect to the channel. These ventilation structures are used for both supplying air during maintenance and additional infiltration (Lightfoot, 2001). As a holistic system, water infiltrates into many points of the system as the *qanat* is gravity-fed from the water table (Lightfoot, 1996, 2001; Al-Ghafri et al., 2003).

The diffusion of the *qanat* system has been recorded in many forms across the world, whilst retaining the same fundamental characteristics (Remini et al., 2014). Across the Middle East and North Africa and the Levant (Lightfoot, 1997), this technology has been recorded in Algeria where it is known as *foggara,* and in Morocco, where it is also referred to as *khettara* (Remini et al., 2014; Fattahi, 2015). In Afghanistan, it is called *kariz*, whilst in Yemen, where there are fewer, it is referred to as *Ghail* and *Miyan,* and in Syria Q*anat Romani* (Al-Ghafri et al., 2003; Lightfoot, 1996, 2000; Shams, 2014). It is thought that diffusion of *qanats* across the Middle East spread with the Archaemenid empire, during which time it reached Oman (Martinez-Santos and Martinez-Alfaro, 2012; Shams, 2014; Kamash, 2006, 2012). Later knowledge of the *qanat* system, and subsequent development transmitted to Spain, and onwards to Latin America (Martinez-Santos and Martinez-Alfaro, 2012; Lightfoot, 2000) where they are largely referred to as *galarias*, although other names such as *puquio* and *matrit* also exist (Al-Ghafri et al., 2003). The success of *qanats* to survive into the twenty-first century, as indicated by the number of functional *qanats* in each country, varies significantly. Spanish *gallerias*, such as those found in Madrid, have long-since been replaced by municipal water systems (Martinez-Santos and Martinez-Alfaro, 2012). Even preceding current conflict, similar significant declines of *qanat*-based systems have completely disappeared in Syria, and in Yemen (Remini et al., 2014; Lightfoot, 2001). However, in countries such as Iran, Oman, Afghanistan, Pakistan, China and Azerbaijan, *qanats* still play a significant role as a sustainable water technology (Hamidian et al., 2015). Notably, in many cases, the *qanat* is operational in low-density and rural environments, and less in urban areas (Fattahi, 2015).

Despite core similarities between the *qanat* systems, adaptations in the technology have varied from context to context with variations in depth reflecting hydrological differences, or differences in the distance between the shafts. For example, the average distance between service shafts is 13 m for the Algerian *foggara*, 18 m for the *qanat* and *karez*. Channel length similarly differs from 12 km in Oman to several times that in Iran (Al-Ghafri et al., 2003). The *foggara* is often about 30 m deep, with the deepest recorded at 300 m for the Iranian *qanat* (Remini et al., 2014; Hamidian et al., 2015). Whilst there are notable similarities between the systems, the diffusion of *qanats* has resulted in adaptations to local environments, cultures and contexts (Hamidian et al., 2015). Hamidian et al. (2015) have defined a classification of *qanats* according to five criteria: length and depth; topography; geographical situation; discharge and source.

Table 2
Shows the distribution of *aflaj* and size of region (Aquastat, 2008).

Regions	Al Batinah	Al Dhakliah	Al Dhahera	Al Sharqiah	Musqat	Total
Area (ha)	5594	7895	3527	4326	225	21606
# of *falaj*	1209	501	473	661	173	3017

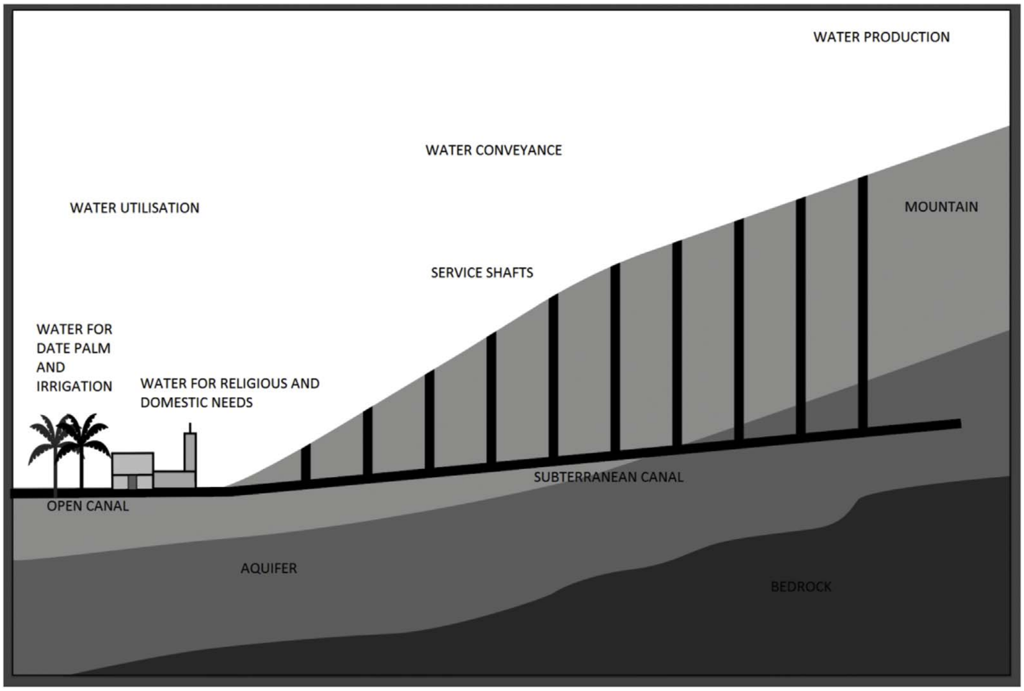

Fig. 1. A typical *aflaj* system as it taps into the water as represented by the darker grey (adapted from Al-Ghafri et al., 2003:p32).

2.2. The daudi aflaj in Oman

The *aflaj* has widespread use in Oman accounting for one third of all irrigation (Al-Ghafri, 2008). Cited in Al-Marshudi (2007), an inventory of *aflaj* by the Omani Ministry of Regional Municipality, Environment and Water (MRMEW) (2002) reports that there are four thousand one hundred and twelve *aflaj*, of which three thousand and seventeen are still in use (Al-Marshudi, 2007; Remini et al., 2014). As shown in Table 1, the distribution of the *aflaj* varies regionally, with the majority concentrated in the region of Al Batinah, in the north of Oman, which has groundwater that supports one-third of Oman's population (FAO, Aquastat, 2008). As seen in Table 1, *falaj* distribution is variable, and largely dependent on geology and physiography of the region (Lightfoot, 2000). The arid mountain area in Northern Oman is largely comprised of gravelly soils and alluvial fans, and therefore hosts many *aflaj* and oases. Similarly, a high frequency of *falaj* and related irrigated agriculture can be found in the Accumulation Plains such as the Batinah Plain, on the Northern Coast of Oman, which hosts almost half of the cultivated area of Oman (as shown in Table 2) (Al-Hashmi, 2013).

Table 2 shows the distribution of three types of *aflaj* which function in Oman: the *daudi aflaj* (*qanat*), the *ghaili* (a channel sustained by *wadi* baseflow) and the *aini* (spring-fed) (see Al-Ghafri, 2008 for diagrams of the different *aflaj* system). The only system which is relevant to this article is the *daudi alfaj* (the *qanat* system) which is the focus.

Hinging on the development of date palm cultivation and oases, the *aflaj* system creates a microclimate in arid areas (Al-Ghafri et al., 2003; Remini et al., 2014). Dates still account for the largest proportion of agricultural land use in Oman (FAO, 2008) which is still almost entirely watered by the *aflaj* (Al-Marshudi, 2001). The date plays many roles in Oman such as: animal feed, fertiliser, income, and in making building materials (Al-Marshudi, 2002). It is also crucial for food and nutritional security (Al-Marshudi, 2002).

The use of water is governed by strict hierarchies of allocation (Al-Ghafri et al., 2003; Sutton, 1984; Birks, 1984). As illustrated by Fig. 1, after conveyance, water is first used for religious, community and social purposes (Dutton, 1989; Al-Ghafri et al., 2003). Water is then used for agricultural purposes; firstly for perennial crops and date palms and then for seasonal crops (Dutton, 1989; Al-Ghafri et al., 2003; Al-Marshudi, 2001). This system ensures that people's basic needs are met. Water is either owned or rented and is allocated within the community by payment per unit of time called an *athar* which equate to roughly 30 min (Al-Ghafri et al., 2003). Traditionally, the local community is responsible for the upkeep of their *aflaj* system which is paid for by the rent per *athar* (Dutton, 1989; Al-Ghafri et al., 2003). Therefore, the *aflaj* system is governed by a set of social norms and defined rules for the use and access to water (Al-Ghafri et al., 2013; Dutton, 1989). However, community knowledge in maintaining the *aflaj* is disappearing, which coincides with a rise in individualistic practices and over-extraction of groundwater (Al-Ghafri et al., 2003). Agricultural water extraction for irrigation has resulted in a decline in groundwater levels and in *falaj* flow in many regions of Oman (FAO, 2008). One case study from Al-Marshudi (2007) evidences declines of average water flows in four *falaj* in Northern Oman between 1997 and 2003. One *falaj* water flow fell from 143 l/s in 1997 to 49 l/s in 2003; the other *falaj* have experienced similar declines in yield.

3. Traditional knowledge systems and the *aflaj*

3.1. Traditional knowledge and hydraulic heritage systems

The foundation of *aflaj* water management is the traditional knowledge that reproduces the rules and norms of governance of these traditional systems, sometimes also referred to as hydraulic heritage systems (Harandi and de Vries, 2014). Davis (2006: 1) defines traditional knowledge as an epistemological system which evolved in 'close interdependence among knowledge, land and spirituality'. According to Laureano (2001:22), traditional knowledge focuses on a unitary understanding of a system which represents both 'practical (instrumental) and normative knowledge concerning the ecological, socio-economic and cultural environment'. This 'unitary ecological system' is interconnected with commons management (or the CPR) and a 'strong cohesion between socio-technical systems' and the embedded social, historical development which has been generationally transmitted and reproduced (Laureano (2001: 22). Critically, the traditional knowledge itself, exists as an epistemologically distinct and a complex system which 'cannot be reduced to a mere list of technical solutions and restricted to a series of different applications according to the results to be attained' (Laureano, 2001: 22; Davis, 2006:1). Traditional knowledge is reproduced through oral histories and oral traditions which transmit community laws, beliefs, cultural values and agricultural practices (Mershen, 2010; UNCBD, 1992).

The *aflaj* system roots itself within this tradition of oral transmission of knowledge. Roles within the *aflaj* management hierarchy are inherited, and knowledge is passed generationally (Sutton, 1984). However, Al-Ghafri et al. (2003); Al-Ghafri, (2008) reports that traditional knowledge has begun to disappear. Al-Ghafri attributes the decline of knowledge to two reasons. Firstly, farmers have become more passive towards the *aflaj* which means that the knowledge for *aflaj* maintenance and management has remained only with the older generation: the younger generation have no interest in the system (Al-Ghafri et al. (2003) citing results of surveys by MRMEWR). Secondly, there is 'a trend that technical knowledge about the *aflaj*, including the traditional time measurement methodologies and *aflaj* construction and management, remain mostly with the older generations' as they have not successfully shared relevant knowledge with the younger generations (Al-Ghafri, 2008: 83). In this case, the breakdown of intra-generational knowledge sharing has resulted in a breakdown of the transmission of traditional knowledge (Al-Ghafri et al., 2003; Al-Ghafri, 2008). This impacts how communities interact over the *aflaj* and consider the place of the *aflaj* within community-based management, presenting an obstacle to collective action.

3.2. Traditional knowledge systems and collective action in modernity

To consider the *aflaj* as a basis for collective action for sustainable water management, we need to examine how the traditional knowledge systems embed collective action within them. Under the CPR framework, this collective action provides a mode of preventing over-extraction and promote sustainable use of the system, such as an aquifer. Ostrom (1990) defined collective actions as having multiple attributes. Firstly, institutions for collective action need to have clear water rights with clearly defined group boundaries which match local conditions and are respected by outside authorities. Secondly, collective action institutions need to ensure that anyone affected by the rules are able to influence them and that they are inclusive of every part of society. Thirdly, sanctions are in place to punish rule-breakers, provide dispute resolution and provide social controls to modify individuals' behaviour within the community. In the case of the *aflaj*, the strict rules governing access to water and clear definitions of ownership provide a mechanism for governing access (Sutton, 1984; Al-Ghafri, 2008; Al-Marshudi, 2001). The presence of a strict hierarchy in the form of committees for managing the *aflaj* further ensures participatory mechanisms are in place (Al-Ghafri et al., 2003). Furthermore, sanctions and social pressure govern how people treat the *aflaj* ensuring that it is maintained for the good of the community (Sutton, 1984). Therefore, the *aflaj* can provide a clear foundation for collective management which protects both the CPR (in this case the aquifer), as well as the system *aflaj* for the community and ensures that the water of the *aflaj* is shared equitably.

Commons (1931: 650) originally defined institutions of collective action as the 'liberation and expansion of individual action [governed by] working rules that can, must or may do or not do, enforced by collective sanctions'. These collective sanctions can take the form of institutionalised working rules. However, they can also take the form of social norms and controls on individual behaviour which limit individual action. Many social capital theorists situate notions of social capital within the collective action framework (Ostrom, 2007). Social capital is defined by Bourdieu and Wacquant (1992: 19) as 'the sum of resources, actual or virtual, that accrue to an individual or group by virtue of possessing a durable network of more of less institutionalised relationships of mutual acquaintance and recognition'. Codified within the *aflaj* system are rules and norms that are enforced by social pressure operating within these networks. For example, there are strict rules governing where domestic *aflaj* users can bathe or collect water. With the burden of water collection falling disproportionately on women, in most *aflaj,* to prevent contamination of the water, women have to walk great distances, up mountainous terrain (higher up the hydraulic gradient), to collect water (Mazjoub, 2010) despite having access to *falaj* water in their villages. Strict social controls ensure that this rule is adhered to: households and women would be perceived as dirty by the rest of the village if they used the water that was diverted for other purposes (Mazjoub, 2010). Controls such as these act as behavioural modification through social capital to modify individual behaviour for the good of the community as a whole. Whilst the understanding of social controls on the *aflaj,* or *qanat* systems generally, the influence of social capital on usage of *qanat* technology has been reported in Mustafa and Qazi (2007) study on *karez* and tubewells in Pakistan.

In systems of collective action for *aflaj* management, traditional knowledge systems are able to mediate both formalised institutions, such as administrative and financial organisations, and informal institutions, such as forms of social capital. However, the interactions between social capital and formalised institutions for collective management are further altered by structural factors. The latter influence whether every member sees value in participating in the decision-making process of the *aflaj* and perceives the benefits of their involvement. This thesis is supported by Ishihara and Pascual (2013) theory that structural power dynamics of communities can explain why collective action can equally succeed or fail in areas in which there is strong social capital. Ishihara and Pascual (2013) further distinguish social capital from social structure in the constitution of collective action and suggest that social capital is something that mediates institutions and agents rather than something that is part of institutional arrangements. Adeel (2008) conceptualises that traditional knowledge governs the rules and norms within communities, as a form of social capital. To apply this thesis to the *aflaj*, traditional knowledge systems, functioning as social capital, can mediate the individuals, social structures and institutions through the provision of a coordination function to determine the outcome of collective action. This coordination function is critical to determining the success of collective action for sustainable management of the *aflaj*; social capital determines not only how these rules are enacted within the community space, but also which actors create the rules, which actors enforce them, and which are excluded from their creation. In summary, the locus for collective action provided by the *aflaj*, embodied in traditional knowledge, provides a co-ordination function for sustainable management of CPR (Meinzen-Dick & Bruns, 2000; Ostrom, 2007; Adeel, 2008; Remini et al., 2014).

4. Traditional knowledge systems and changing institutions

In terms of coping with physical water scarcity, Ostrom (1990) noted that most obstacles to collective action are primarily social and require a context-specific analysis. In the case of the *falaj*, the tendency of current literature to characterise them as a readymade system for collective action (and social capital) ignores the heterogeneous factors affecting the entire *falaj*. One of the determinants of obstacles to collective action is how responsive traditional knowledge systems are to change. To consider this adaptability, we need to deconstruct Adeel (2008) characterisation of the *aflaj* as the locus of traditional knowledge. Multiple institutions, both formal and informal, and individuals, interact within this traditional knowledge system (Adeel, 2008). Whilst the community-based management systems of the *aflaj* are regarded as the most effective and efficient way of distributing resources amongst rural communities, the diversification of institutions interacting over water, after the modernisation of agriculture resulted in competing interests over water (Al-Marshudi, 2002; Al-Ghafri et al., 2003), mean that traditional knowledge systems need to adapt to this challenge.

In *Beyond Panaceas of Water Institutions*, Meinzen-Dick (2007) constructs a framework which examines the different actors which have responsibilities for management of water: the market, water users' associations and the state. Historically, *aflaj* management systems have operated outside of state institutions and under their own customary

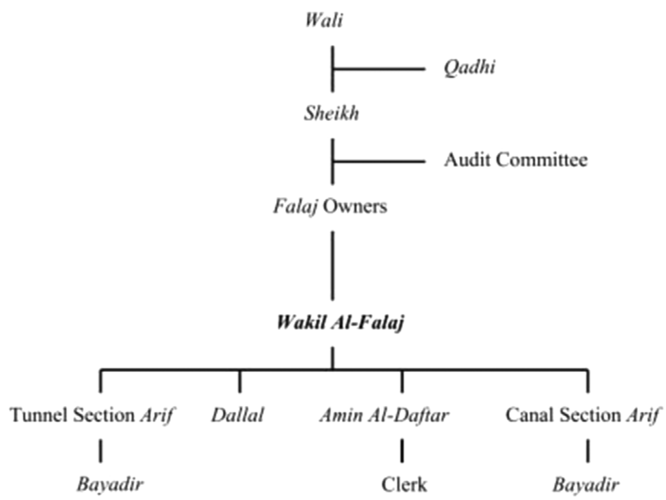

Fig. 2. Management of a large falaj (Al-Ghafri et al., 2003: 31).

laws (Dutton, 1989; Lightfoot, 2001). However, modernisation in Oman has altered the interactions between institutions (Al-Marshudi, 2002). This shift has had an impact on the role of traditional knowledge systems which now have to function in a multi-institutional framework. Firstly, in the last few decades, the state has taken over more responsibility for the upkeep of the *aflaj*. Recognising the importance of the *aflaj*, the government has performed emergency renovations and partly paid for their upkeep (Al-Ghafri et al., 2003). However, these interventions, whilst improving the physical condition of the *aflaj*, have also had indirect impacts such as increasing passivity towards the *aflaj* in communities (Al-Ghafri et al., 2003). Government intervention has also changed the expectation of who should pay for maintenance from the local community to the government. Secondly, the changing role of the market has altered the way that communities have interacted over water (Al-Marshudi, 2001, 2002). These changes to market interactions have occurred in two ways. Modernisation has led to changes in crops grown and the rise of 'cash crops' consistent with a shift away from subsistence agriculture towards irrigated agriculture for commercial use (Al-Ghafri et al., 2003; Dickhoefer and Schlecht, 2010). This has followed a shift towards tubewell irrigation due to technological advancements (Dutton, 1989; Lightfoot, 2000; Mustafa and Qazi, 2007).

Furthermore, most notably, in Oman, the shift in the role of date markets has altered the interactions between traditional knowledge systems and collective action (Al-Marshudi, 2002). This transformation has opened up date markets to wider trade between Gulf Cooperative Council (GCC) countries (Al-Marshudi, 2002). These transformations in trade have polarised farmers between commercial, land-owning farmers and poorer, subsistence farmers (Al-Marshudi, 2002). This transformation in institutional interaction – between traditional date markets and commercial date markets – has altered the way that farmers cooperate over resources.

Therefore, changes to traditional systems from pressures to interact with markets have excluded poorer and subsistence farmers from many forms of water institutions – being limited in their access to the marketplace and unable to access modern irrigation systems necessary to irrigate crops (Lightfoot, 2001; Al-Marshudi, 2002). In cases where traditional knowledge has not been able to adapt or has not been given a place in modern agricultural society, then the necessary conditions for collective management of resources start to break down (Ostrom, 1990; Meinzen-Dick, 2007). This breakdown is largely due to a weakening of clearly defined water rights which have been enshrined in customary laws (and related social norms) which govern the *aflaj*, and governmental and industry rights, which also control the management of the CPR through controlling access and availability of groundwater (Al-Marshudi, 2002; Meinzen-Dick and Bruns, 2000). Therefore, shifting away from purely community-based management, could limit the capacity of communities for collective action.

5. Structural factors, knowledge systems and the *aflaj*

The way that traditional knowledge systems mediate institutions, social capital and structural factors revolving around the *aflaj* determines the outcome of collective action (Mustafa and Qazi, 2007). Many current studies of the *aflaj* do not consider the institutional structures required for the dissemination of traditional knowledge. In Oman, very strict hierarchical structures dominate access and equity. Whilst tube-wells and access to markets might have polarised communities along the lines of ownership and affordability (Al-Marshudi, 2002), structural inequalities are further entrenched in the systems of maintenance of the *aflaj*. These systems further add to the burden of those who, due to their lower social position, are most at risk of impacts in the case of climate events such as precipitation deficiency (Mustafa and Qazi, 2007). However, a contrast needs to be drawn between hierarchies which have arisen under modernisation and hierarchies which exist under a traditional system of government. Under a traditional system, these formal institutions – headed by the *wakil* (person who acts as representatives) – form a comprehensive system to manage every aspect of the *falaj* (see Fig. 2).

The interactions between these aspects of traditional knowledge systems – social capital, social structure and institutions – determine whether the outcome is a successful and inclusive system. An example of this inequality can be seen in the local *bayadir* who are responsible for the physical labour to maintain the *aflaj* (Mazjoub, 2010; Al-Ghafri et al., 2003; Sutton, 1984). Traditionally, as represented in Fig. 2, the *aflaj* system is maintained by *bayadirs*, who, like the rest of the members of the social hierarchy, are born into these roles (Sutton, 1984). As shown in Fig. 2, under a traditional system, this social hierarchy is delegated to a *wakil* is in charge of the *falaj*; however, the *bayadirs* are, in the structural ranking, positioned at the bottom of the hierarchy. In cases of drought years, the traditional expectation of a community is often that the *bayadirs* will work for little or no money as the yields from the *falaj* are lower, and the systems of rent changes, and, therefore, the cost to the landowners supplying water is greater (Birks, 1984). Furthermore, perceptions of the work of the *bayadirs* is often viewed as dangerous. Therefore, with the increase in options available to them, many males who are from a line of *bayadirs*, make the decision which will most benefit them rather than the community: migration for better paid jobs (Birks, 1984).

Clearly in this feature, the *aflaj* system is deviating from Ostrom's definition of collective management which is based on the inclusiveness of the management systems and the provision that those affected by the rules participate in them. However, in this case, the *bayadirs*, perceiving their interaction in the community as restricted and the *falaj* system of no benefit to them, instead abandon the *falaj* as the benefits given from the work supplied no longer provides the maximum utility to them (Birks, 1984). As Ishihara and Pascual (2013: 11) theorise 'community members may tend to act collectively only when they can formulate common knowledge that comes with the idea that acting collectively creates benefits that outweigh costs'. This thesis is borne out in the conclusions of Dutton (1989), Sutton (1984) and Birks (1984) although none of them explicitly tackle the structural factors involved in the success or failure of collective action. In their work in the eighties, their studies found that there was a need to alter structural factors to maintain the *aflaj* system. For example, Dutton (1989) suggests that payment for the *falaj* upkeep is redistributed. Dutton (1989) suggests that the owners of water rights also financially contribute to the upkeep of the *falaj* in order to fully recover the costs of maintenance. However, changes such as these, whilst being more structurally egalitarian, might be met with opposition from the community (Dutton, 1989).

The structural factors, as shown in Table 3, which have arisen (or worsened) during modernisation exemplify the thesis that traditional

Table 3
Shows Structural Factors reported in texts on *aflaj* and *qanats*.

Structural Factor	Example	Source
Economic	*Bayidir* paid less or free labour expected during drought years	(Birks, 1984; Mazjoub, 2010; Sutton, 1984; Mustafa and Qazi, 2007)
	Differences in rights to landowners and subsistence farmers	
Gender	Women have to access water from further to avoid being perceived as dirty	(Mazjoub, 2010)
Inequality	Unequal cost of upkeep and maintenance	Dutton (1989)

knowledge systems require flexibility and re-invention to adapt to changes in the community and provide optimum livelihood opportunities for *bayadirs*.

In cases where traditional knowledge systems are inflexible to change, they start to break down as seen in the case of the *bayadir*. The adaptability of traditional knowledge systems to the changing demands of the *bayadir* are key to maintaining the system. If the system is not able to respond, then, as Birks (1984) reported, there will be an increase in migration out of the area as the *bayadirs*, not seeing the value of their involvement (economically or socially), seek systems which maximise their own utility (Birks, 1984; Dickhoefer and Schlecht, 2010). The adaptations of knowledge systems to change, and the inclusion of minority rights into collective action systems, increase what Davies (2006) refers to as 'transformative' capacity of communities to water scarcity and drought.

6. Limitations and influencing factors of *aflaj* persistence

This section addresses the other factors which interact within the hydraulic heritage system, and associated knowledge systems, which may lead to the success of the system or reduce the *daudi aflaj*'s ability to adapt and transform to modern pressures. Many of these factors have been discussed in more detail by *aflaj* and *qanat* scholars (Harandi and de Vries, 2014; Remini et al., 2014; Lightfoot, 2000; Mustafa and Qazi, 2007; Al-Marshudi, 2002) but could serve as an example of external factors which push the *aflaj* towards obsolescence.

Firstly, climatic variability, decreasing rainfall and increasing evapotranspiration (resulting from increasing temperature) due to global climate change might decrease recharge to these systems. As the *aflaj* is particularly sensitive to water table fluctuations, and labour costs intensify, the reduction in recharge rates may push these systems out of function, either seasonally or completely (Al-Ghafri, 2008). Secondly, one of the biggest threats to both the physical infrastructure of the *aflaj* and the institutional and traditional management systems around it is the proliferation of tubewells in the region. According to available 2007 figures, the extraction of water from wells is now 67% of total groundwater, compared to 33% from *falaj* (Aquastat, 2008). Tubewells are a largely individualistic technology, in contrast to the collective action for the protection of CPR provided by the *aflaj* (Mustafa and Qazi, 2007). As tubewells are extractive to a much greater degree than the *aflaj*, they allow much greater exploitation of groundwater, which also leads to falling water tables and regional depletion of groundwater (Zekri & Al-Marshudi, 2008).

Examples of the obsolescence of *qanat* systems are seen in many countries. In Yemen, Lightfoot (2001) reports that the *Ghayl* or *Miyan* system has declined, in part because of the tubewell which has led to many systems being abandoned. Similarly, in Pakistan, a study by Mustafa and Qazi (2007) found the drawdown of the water table, below the depth of the motherwell, led to most *karez* being unable to produce water. Again in Morocco, Garcia-Rodriguez et al. (2014) found that lower water tables have led to approximately 260 *khettaras* in the one region being unable to produce water. These factors need considerable attention as, regardless of the intention of communities to maintain an effective traditional management of *aflaj*, without much greater investment to deepen the system, the technology may no longer be able to produce water.

However, even with the proliferation of tubewells and related changes to the water table, the case for the importance of traditional knowledge as a locus for collective action is not obsolete. In the case of managing the entirety of the CPR (the aquifer) there is an extent to which traditional knowledge can serve as a driver for collective action through the promotion of norms and rules to govern modern technology, such as tubewells. There are a few notable examples in the literature which suggest that there are cases where *qanat* technology had historically been the primary form of water management, similar rules have been largely transposed to manage tubewells. In Yemen, prior to the current conflict, there has been an adaptation of *qanat* rules to sustainable and equitable management of diesel tube-wells (Van Steenberg et al., 2011). Similarly, Mustafa and Qazi's (2007) study on social capital and management of the *karez* in Pakistan mentions that whilst the replacement of *karez* with tubewells has largely increased inequality, there is some mention of the translation of *karez* rules into a collective action framework for tubewell management. In making the case for adaptable traditional knowledge systems, it should therefore be considered whether the traditional knowledge systems still have a role to play in managing the commons, even after their technology has become obsolete.

7. Conclusion

The tendency of traditional knowledge systems to be represented as dichotomous with modernisation has often dominated discourse over the *aflaj* and other traditional systems. As has been demonstrated, 'the inertia of tradition' is not a necessary condition for traditional knowledge. These epistemologies are often dynamic and evolutionary systems which constantly adapt to emerging threats to the resilience of their communities. However, the flexibility of traditional knowledge systems to respond to increasing pressures of modernisation – such as the diversification of institutions and increasing interactions with, previously external institutions - will determine the way that communities manage common resources such as the *aflaj*.

What is important to note is that there is no 'silver bullet' to protect Oman's remaining *aflaj,* and promote sustainable water management, but instead the potential of traditional knowledge to adapt to modernisation can add significant benefit to institutional arrangement and governance of these systems. Therefore, further understanding of methods for managing the *aflaj* is needed. Common resources, such as time-sharing per *athar*, strict social hierarchies and subsistence agriculture, are in transformation. This transformation will determine livelihood security, resilience to drought and long-term sustainability of resources. If traditional knowledge systems, promoting equitable governance of finite resources, are not able to adapt, then they are likely to continue to decline. This adaptation can take many forms such as establishing a new equilibrium to accommodate increasing market pressures, or inclusion of minority rights by creating more inclusive systems so that *bayadirs* continue to see value in their involvement. Unfortunately, the rise of passive attitudes towards the *aflaj* and difficulties of these systems to adapt to different methods of management, threatens the ability of traditional knowledge systems to maintain its fundamental place in Oman. Management of scarce water resources is a key challenge for Oman's stability: both at a local rural level and a national level. Unless efforts are made to maintain and transform systems which are locally appropriate, efficient and sustainable, Oman will face greater pressures from modernisation.

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